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FOR AERONAUTICS

REPORT No. 166

THE AERODYNAMIC PLANE TABLE

By A. F. ZAHM



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Advisory Committee
for Aeronautics.

AERONAUTICAL SYMBOLS.

1. FUNDAMENTAL AND DERIVED UNITS.

	Symbol.	Metric.		English.	
		Unit.	Symbol.	Unit.	Symbol.
Length...	l	meter.....	m.	foot (or mile).....	ft. (or mi.).
Time.....	t	second.....	sec.	second (or hour).....	sec. (or hr.).
Force....	F	weight of one kilogram.....	kg.	weight of one pound....	lb.
Power....	P	kg.m/sec.....		horsepower.....	HP
Speed.....		m/sec.....	m. p. s.	mi/hr.....	M. P. H.

2. GENERAL SYMBOLS, ETC.

Weight, $W = mg$.

Standard acceleration of gravity,

$$g = 9.806 \text{ m/sec.}^2 = 32.172 \text{ ft/sec.}^2$$

Mass, $m = \frac{W}{g}$

Density (mass per unit volume), ρ

Standard density of dry air, 0.1247 (kg.-m.-sec.) at 15.6°C. and 760 mm. = 0.00237 (lb.-ft.-sec.)

Specific weight of "standard" air, 1.223 kg/m.³ = 0.07635 lb/ft.³

Moment of inertia, mk^2 (indicate axis of the radius of gyration, k , by proper subscript).

Area, S ; wing area, S_w , etc.

Gap, G

Span, b ; chord length, c .

Aspect ratio = b/c

Distance from $c. g.$ to elevator hinge, f .

Coefficient of viscosity, μ .

3. AERODYNAMICAL SYMBOLS.

True airspeed, V

Dynamic (or impact) pressure, $q = \frac{1}{2} \rho V^2$

Lift, L ; absolute coefficient $C_L = \frac{L}{qS}$

Drag, D ; absolute coefficient $C_D = \frac{D}{qS}$

Cross-wind force, C ; absolute coefficient

$$C_c = \frac{C}{qS}$$

Resultant force, R

(Note that these coefficients are twice as large as the old coefficients L_c, D_c .)

Angle of setting of wings (relative to thrust line), i_w

Angle of stabilizer setting with reference to thrust line i_t

Dihedral angle, γ

Reynolds Number = $\rho \frac{Vl}{\mu}$, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi/hr., normal pressure, 0°C: 255,000 and at 15.6°C, 230,000;

or for a model of 10 cm. chord, 40 m/sec., corresponding numbers are 299,000 and 270,000.

Center of pressure coefficient (ratio of distance of C. P. from leading edge to chord length), C_p .

Angle of stabilizer setting with reference to lower wing. $(i_t - i_w) = \beta$

Angle of attack, α

Angle of downwash, ϵ

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Aerodynamical Laboratory, Bureau of Construction and Repair, U. S. Navy

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INTRODUCTION.

For the accurate and expeditious geometrical measurement of models in an aerodynamic laboratory, and for miscellaneous truing operations, there is frequent need for a specially equipped plane table. For example, one may have to measure truly to 0.001 inch the offsets of an aerofoil at many parts of its surface. Or the offsets of a strut, airship hull, or other carefully formed figure may require exact calipering. Again, a complete airplane model may have to be adjusted for correct incidence at all parts of its surfaces or verified in those parts for conformance to specifications. Such work, if but occasional, may be done on a planing or milling machine; but if frequent justifies the provision of a special table. For this reason it was found desirable in 1918 to make the table described in this report and to equip it with such gauges and measures as the work should require.

The working and design drawings for the table were made by my assistant, Mr. Louis Thoms; those for the instruments by Mr. L. H. Crook, who supervised the construction of both the table and the instruments. This report, originally sent to the Chief of the Bureau of Aeronautics and dated April 12, 1922, was submitted by that bureau for publication to the National Advisory Committee for Aeronautics, with the added Figure 4 not in the original.

DESCRIPTION OF THE PLANE TABLE.

The basic apparatus is a smoothly planed cast-iron table, Figure 1, whose top measures 3 by 12 feet and has two parallel T slots along its entire length. Leveling screws are provided for its feet. A boss under its center admits of drilling a hole through its top to bolt fast an object, such as a propeller, which is to undergo verification or heavy static tests. The plane surfaces of the side and end are quite normal to each other and to the top, to serve as bases for T square use.

The linear scale shown on the side of the table serves to measure the movement of an instrument along one of its grooves. Figure 2 shows the method of engraving the scale. A Rivett lathe lying on its side carries a V pointed tool which is moved vertically with the cross-feed to score the scale marks and drawn laterally with the accurate lead screw to space the marks. The lathe is shifted endwise, 2 feet at a time, by aid of an accurate spacing bar clamped to the table, but which need not be described.

THE CONTOUR MICROMETER.

Figure 3 illustrates a plane-table instrument for taking the offsets or topographic measurements of a model's surface or contour line. A column with a massive base is driven along the table by a rack and pinion, as shown, and carries a slide rest along vertical ways planed on its face. The slide rest bears a cross-feed and tool post for holding a dial gauge which is to be moved to all parts of the model's surface or contour. The dial gauge itself and the handwheels of the vertical and cross slides have open decimal graduations reading to 0.001 inch. The slides, including the graduated swivel for sloping the cross-feed, were at first borrowed from a lathe, then were made a permanent part of the micrometer.

The linear travel of the base can be read truly to 0.001 inch with an attached lens focusing on a fine standard scale clamped to the table, or less accurately with a plainer scale screwed to the table or engraved thereon. The present linear scale, engraved on the side of the table, is marked in inches and tenths. A vernier for reading hundredths is screwed to the sliding base and can be slid 0.1 inch along the base for setting to a convenient zero. For finer work the scale is read to hundredths and thousandths, as illustrated in Figure 4, with a dial gauge elastically mounted on the sliding base and having at the tip of its spindle a tooth that can be pressed into the marks on the linear scale.

When an aerofoil is to be verified it is laid on a cradle, as shown in Figure 3, either flat on top of the standards or clamped to their vertical sides, as may seem best. The point of the gauge is then fed crosswise of the model at various sections to measure their offsets. The profile of a strut is measured in like manner.

To caliper an airship model the instrument is used as shown in Figure 5. While the hull rests level on two V blocks, the sharp edge of the dial gauge stem is set, first at the nose of the hull, then at successive points along its side. At each position readings are taken of the distances aft of the nose and from the long axis. To avoid too much pressure of the sharp edge against the model, one stops the cross-feed motion when the dial hand begins to move and reads the offset on the cross-feed scale.

THE VERTICAL KNIFE-EDGE.

An airship hull is sometimes calipered as illustrated in Figure 6. When resting level on paper a vertical straightedge with a recording pencil at its bottom is passed around the model, touching it gently. A contour line is thus drawn from which the offsets can easily be measured to the precision required for a wooden model of large diameter. It is impracticable to construct or keep such bodies accurate to one or two thousandths of an inch in their larger dimensions.

The pencil holder is a small piston sliding in a drill hole coaxial with the knife-edge and pressed down by a small spiral spring. The piston can conveniently be raised and locked to protect the pencil when not in use.

THE PLANE-TABLE PROTRACTOR.

For the setting or verification of wing planes and control planes the instrument shown in Figure 7 is used. This comprises a clamp stand with massive round base and an accurate cylindrical column along which slides an adjustable sleeve supporting a common draftsman's protractor. The radial arm swinging in a vertical plane can be applied to the wing chord to indicate its slope. In ordinary models the wing incidence is adjusted at various sections by rotating the right-and-left-threaded inclined struts of the model, thus changing their lengths. The wing slope can thus be set and measured as accurately as the eye can judge the coincidence of the chord and radial arm.

Sometimes this arm is applied to the wing chord, or to bench marks on the wing, as a simple straightedge; again it may carry sliding jaws each having a sharp tooth or a small lens which is brought to bear on reference marks at the leading and trailing edge. To be set truly to 0.01° , a 5-inch wing chord must, at its extremities, coincide with the straightedge to less than 0.001 inch. A setting true to 0.005 inch is fine enough for the usual wooden airplane model.

SPECIAL USES OF THE TABLE.

The plane table is not infrequently used by the instrument and model makers for measuring or aligning new apparatus. Figure 8 illustrates such use. When the lift weighing mechanism of the new aerodynamic balance was assembled, two sets of guide rods, comprising four rods each, had to be set horizontal truly to one one-thousandth of an inch. Accordingly the mechanism was supported on the plane table as shown. By means of surface gauges the machinist tested the distance of each end of each rod—16 ends in all—above the top of the table. As these ends were adjustable vertically, they were soon perfectly spaced and locked, so as to remain permanently in planes normal to the axis of the balance.

ORDINARY USES OF THE TABLE.

Figure 9 illustrates the ordinary use of the table. Several men can comfortably work on different tasks at the same time without interference, even though some of the models be quite large. To insure accuracy, the measurements on the less permanent models, such as wooden aerofoils, airplanes, and newly made airship hulls, are performed before each test if the tests are separated by any considerable time:

THE AEROFOIL CABINETS.

The laboratory aerofoils, before and after measurement, are kept in special cabinets, as shown in Figure 10. Each model with its template rests on a sliding shelf, so as to be easily drawn forth for inspection. When arranged serially and indexed, hundreds of aerofoils can thus readily be located while being safely preserved. The larger models are at present mounted on the walls of the aerodynamic laboratory, as illustrated in Figure 11.

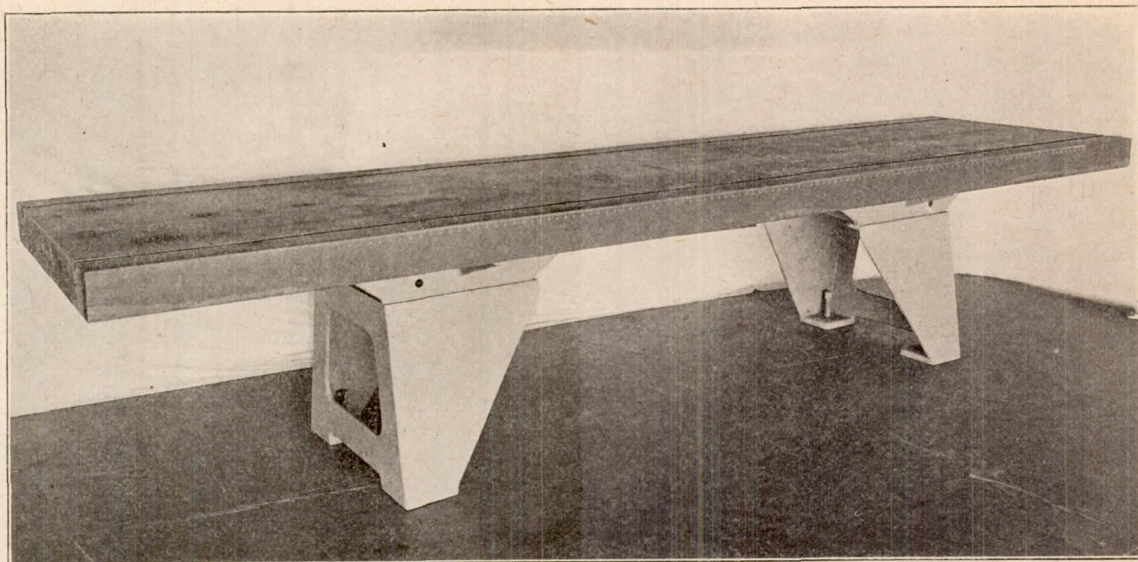


FIG. 1.—The aerodynamic plane table without equipment.

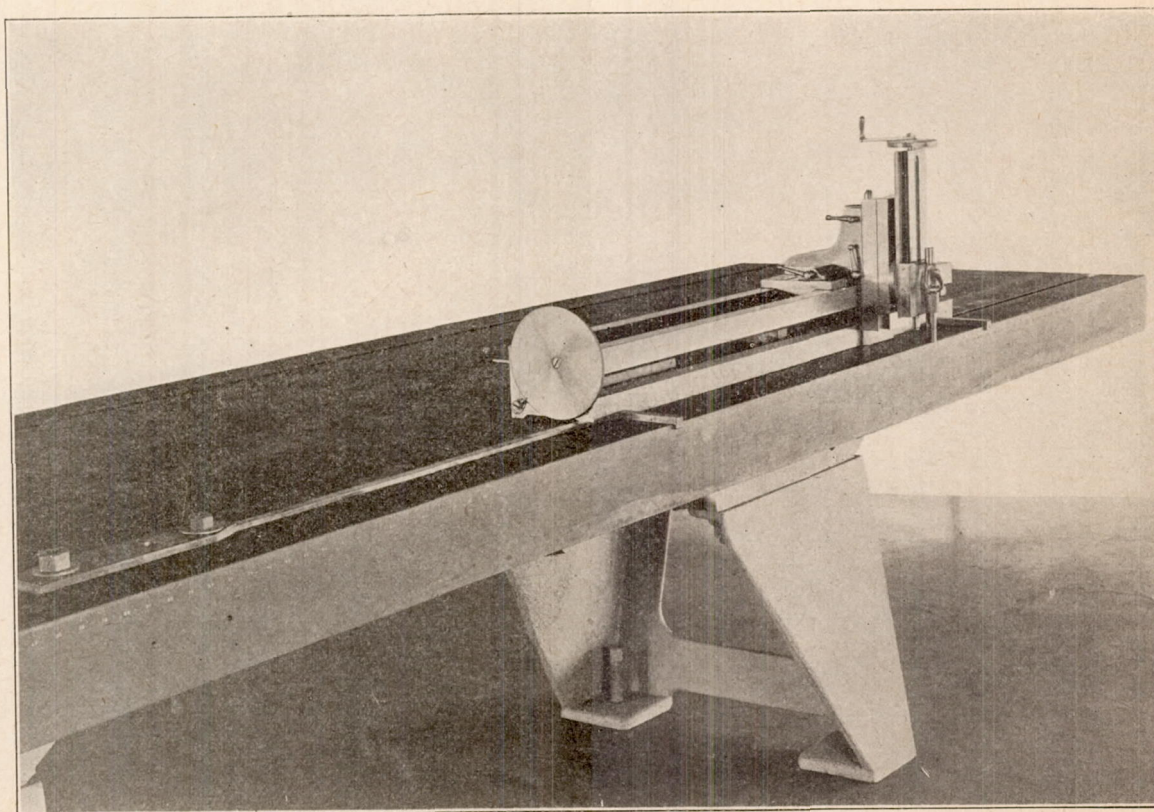


FIG. 2.—Engraving the plane table.

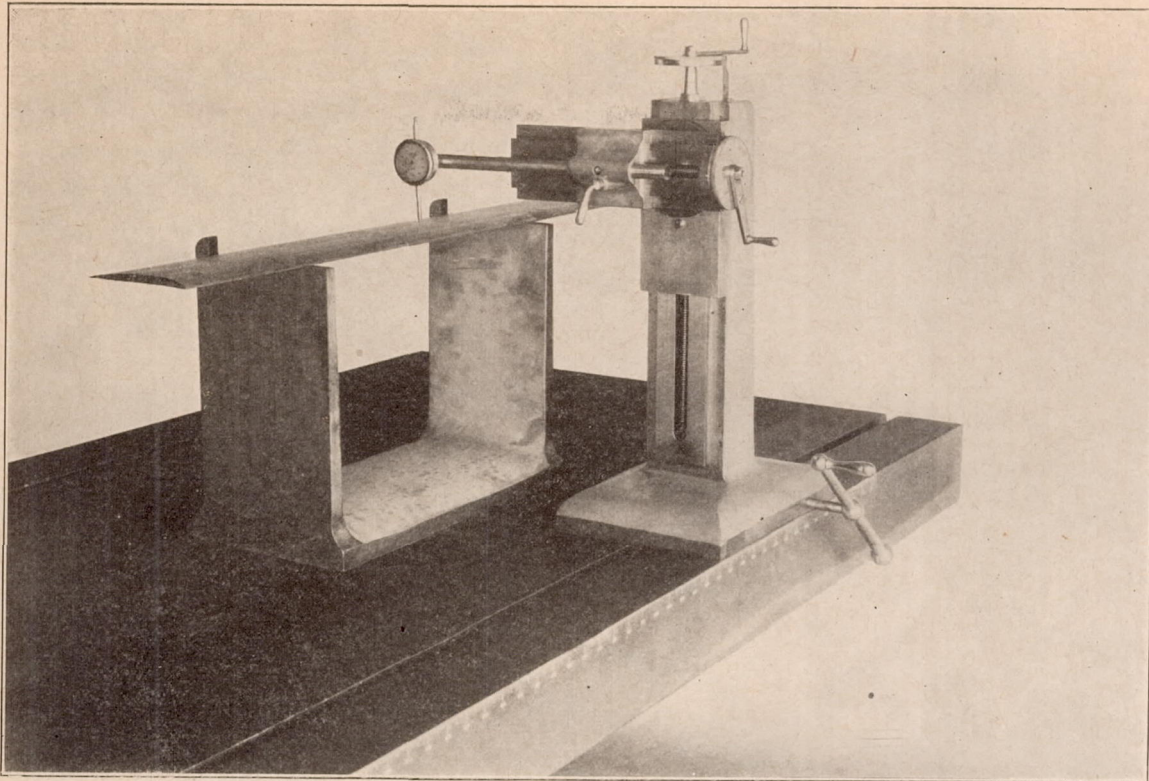


FIG. 3.—The contour micrometer measuring an airfoil.

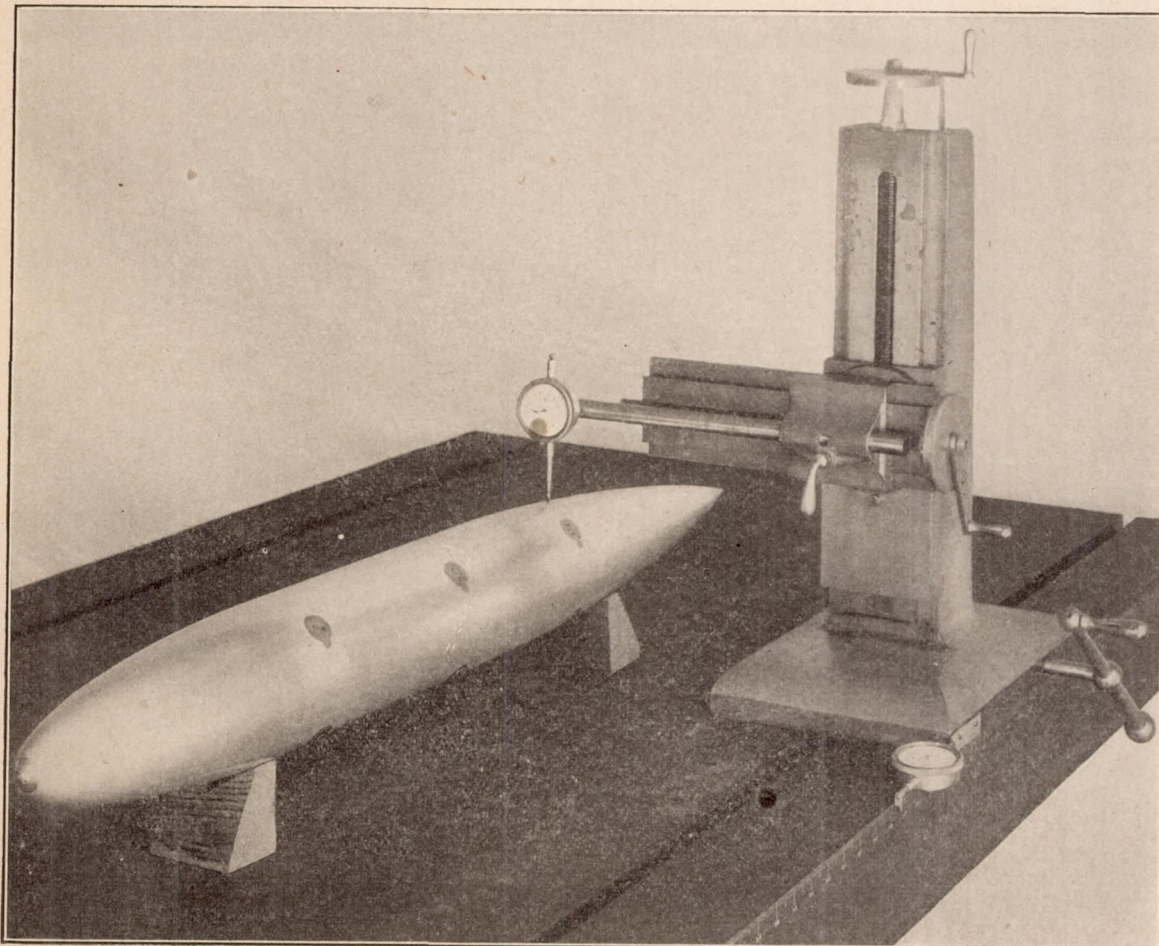


FIG. 4.—The contour micrometer measuring a metal airship hull; measurements true to .001 inch in three rectangular directions.

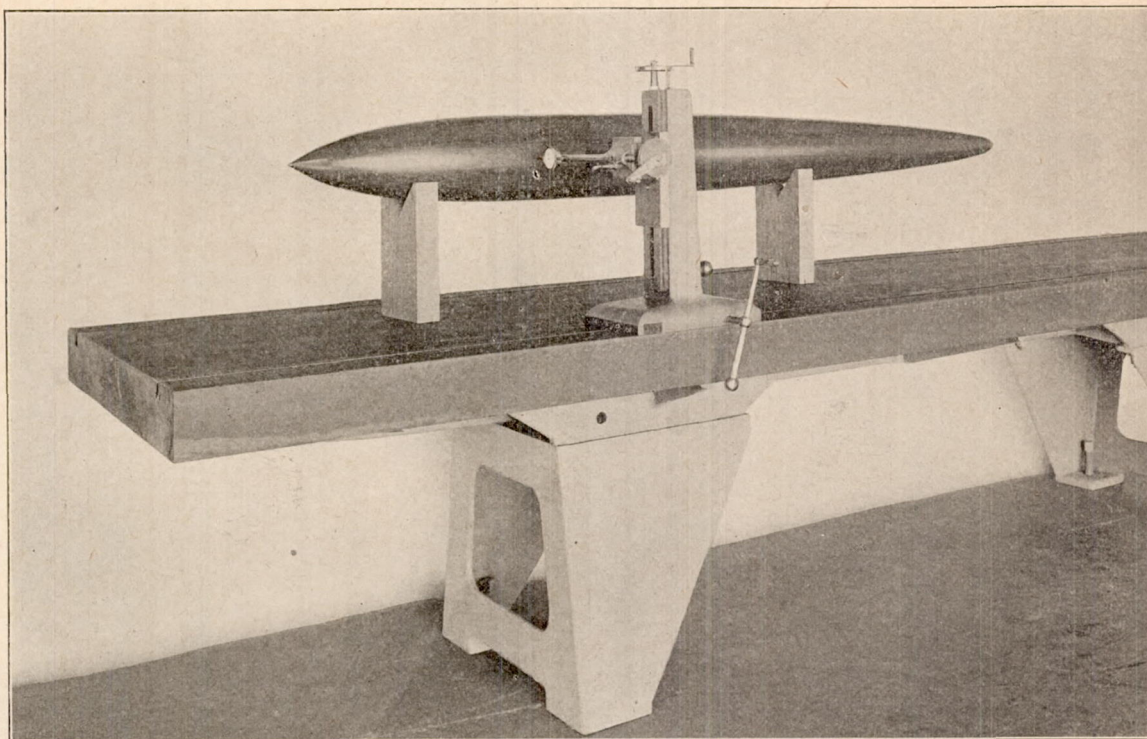


FIG. 5.—The contour micrometer measuring a wooden airship hull : lengthwise scale read with vernier.

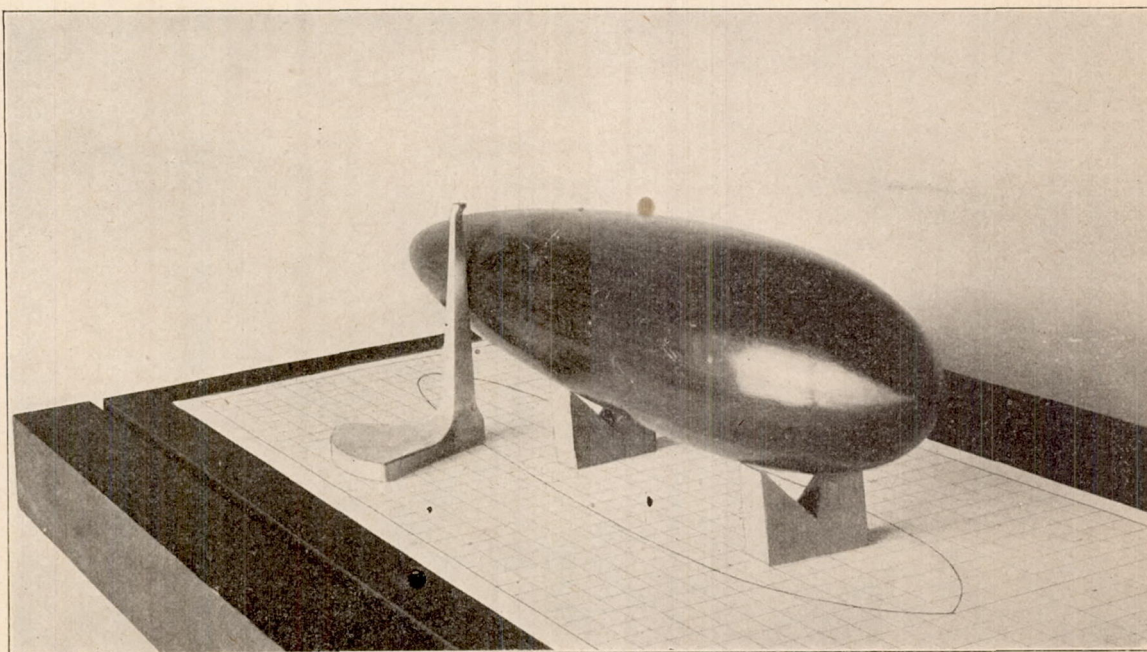


FIG. 6.—The vertical knife edge projecting a contour.

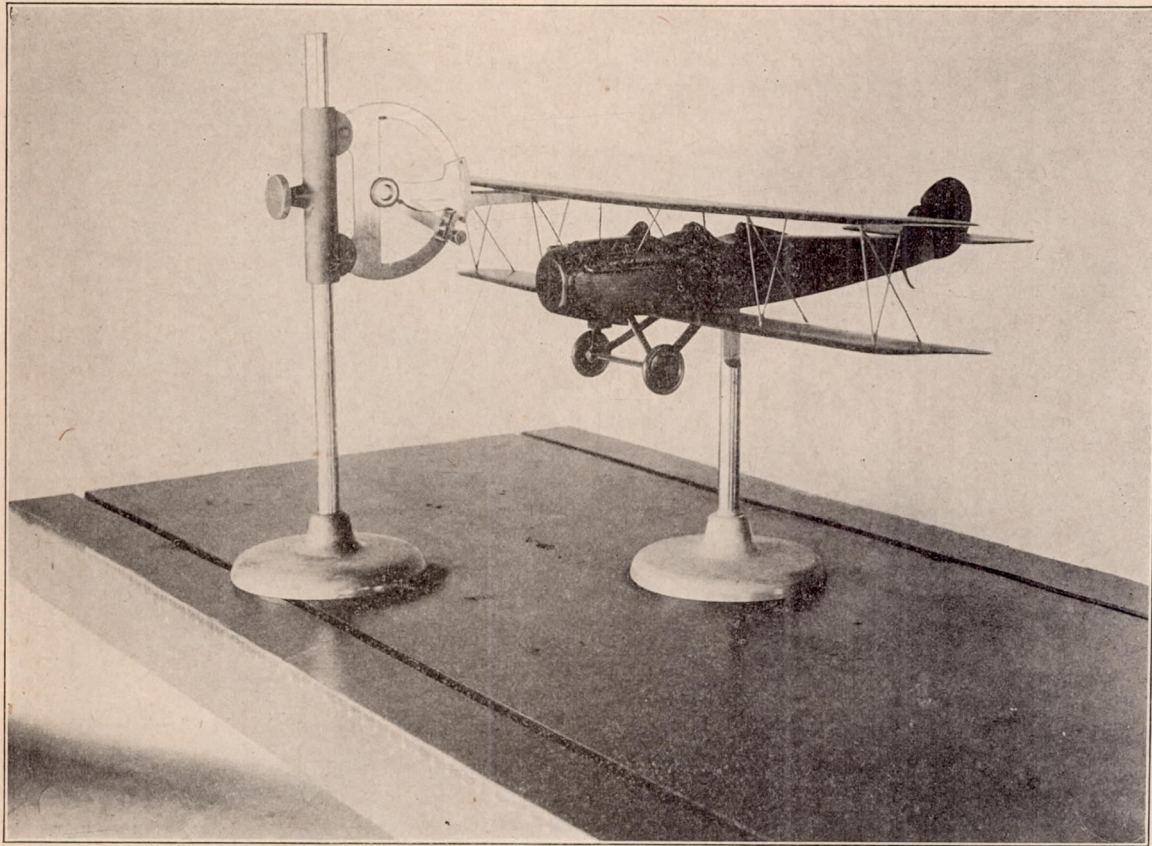


FIG. 7.—The plane table protractor.

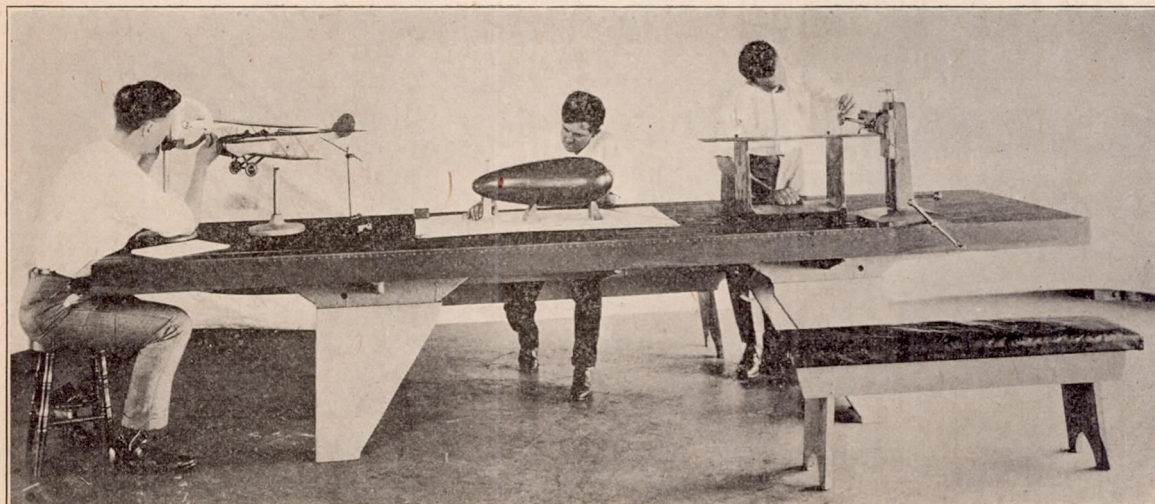


FIG. 9.—The plane table in ordinary use.

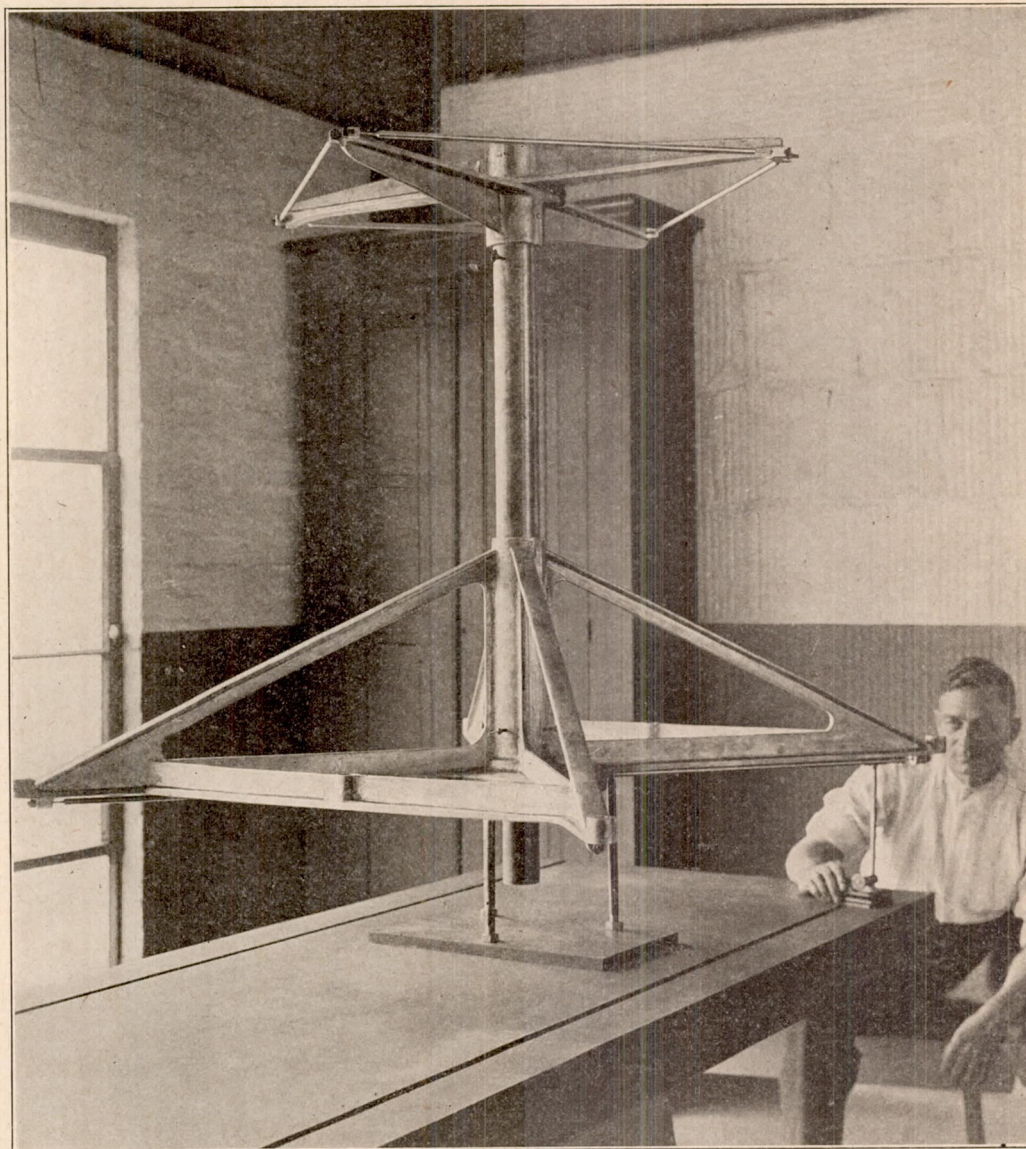


FIG. 8.—A special plane table operation. Adjusting eight rods parallel to a common plane to .001"

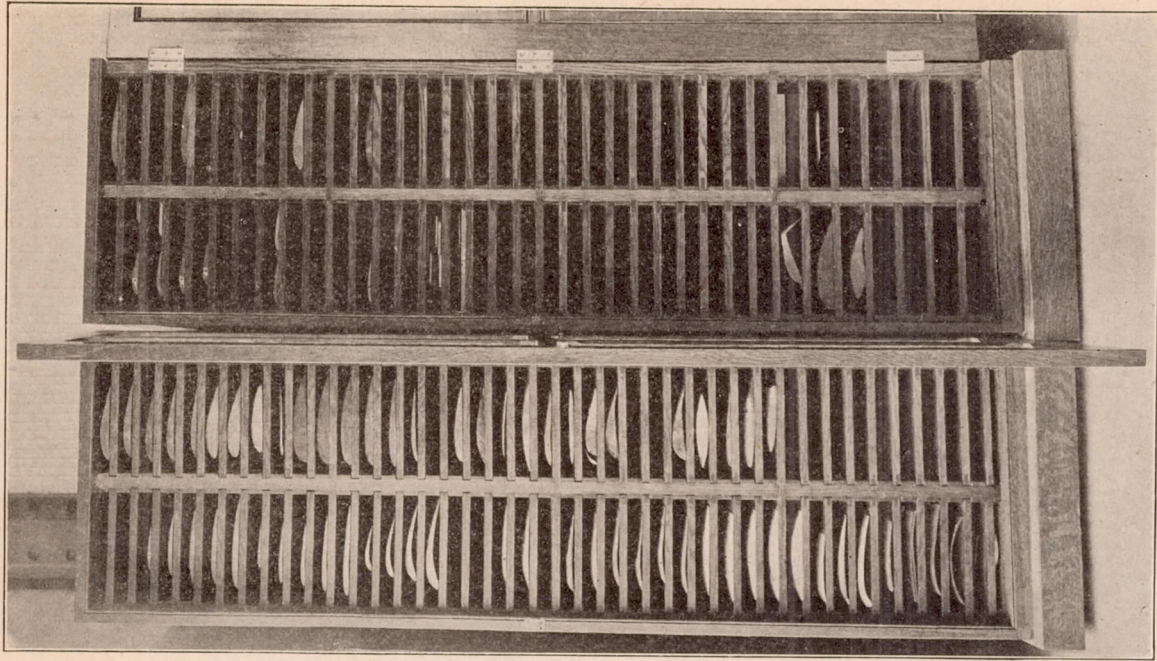


FIG. 10.—The airfoil cabinet.

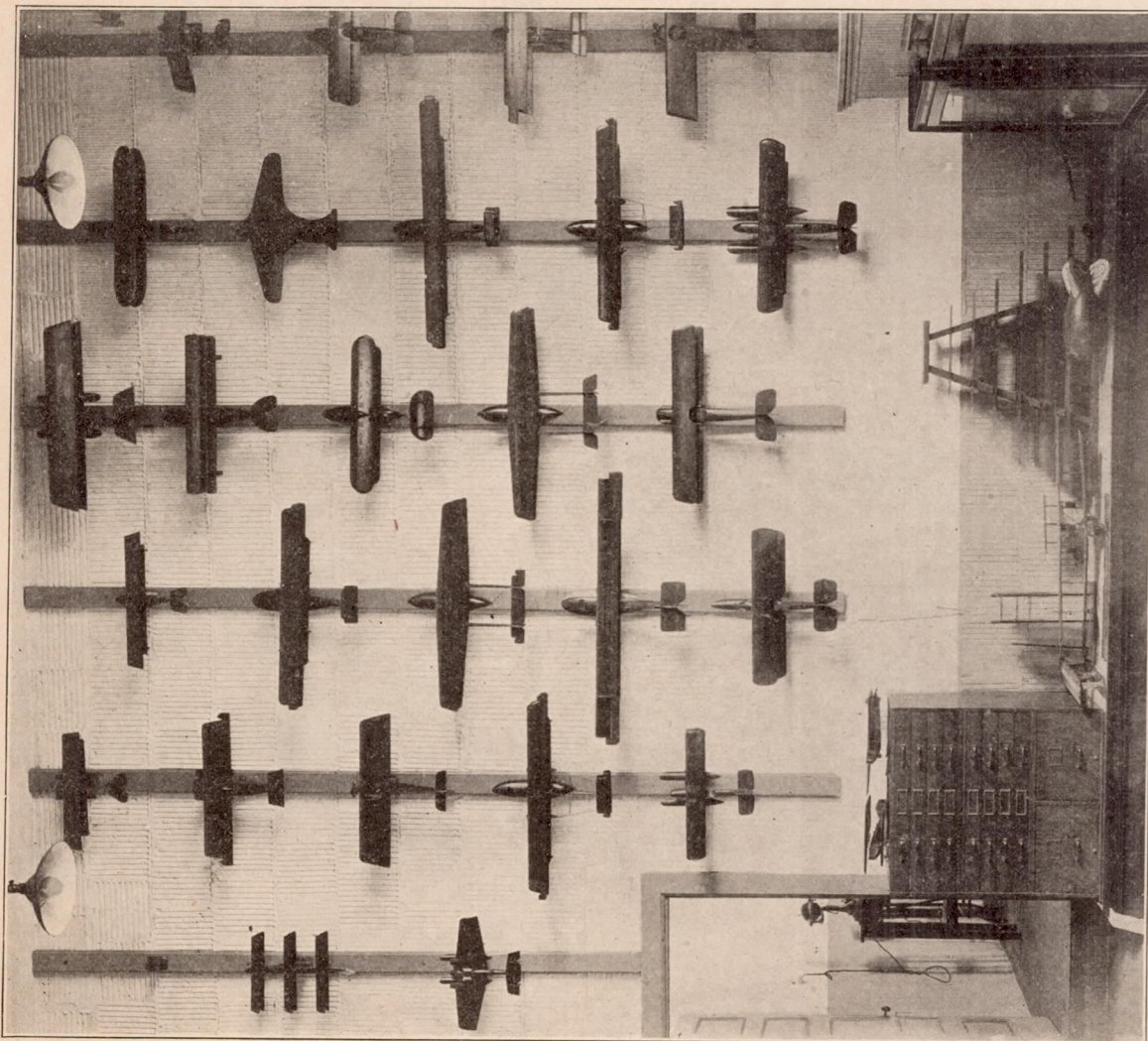
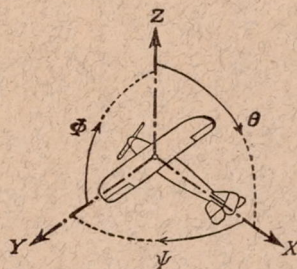


FIG. 11.—Models in storage.



Positive directions of axes and angles (forces and moments) are shown by arrows.

Axis.		Force (parallel to axis) symbol.	Moment about axis.			Angle.		Velocities.	
Designation.	Sym- bol.		Designa- tion.	Sym- bol.	Positive direc- tion.	Designa- tion.	Sym- bol.	Linear (compo- nent along axis).	Angular.
Longitudinal....	X	X	rolling.....	L	Y → Z	roll.....	Φ	u	p
Lateral.....	Y	Y	pitching....	M	Z → X	pitch.....	Θ	v	q
Normal.....	Z	Z	yawing.....	N	X → Y	yaw.....	Ψ	w	r

Absolute coefficients of moment

$$C_l = \frac{L}{q b S} \quad C_m = \frac{M}{q c S} \quad C_n = \frac{N}{q f S}$$

Angle of set of control surface (relative to neutral position), δ . (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS.

Diameter, D

Pitch (a) Aerodynamic pitch, p_a

(b) Effective pitch, p_e

(c) Mean geometric pitch, p_g

(d) Virtual pitch, p_v

(e) Standard pitch, p_s

Pitch ratio, p/D

Inflow velocity, V'

Slipstream velocity, V_s

Thrust, T

Torque, Q

Power, P

(If "coefficients" are introduced all units used must be consistent.)

Efficiency $\eta = T V / P$

Revolutions per sec., n ; per min., N

Effective helix angle $\Phi = \tan^{-1} \left(\frac{V}{2\pi r n} \right)$

5. NUMERICAL RELATIONS.

1 HP = 76.04 kg. m/sec. = 550 lb. ft/sec.

1 kg. m/sec. = 0.01315 HP

1 mi/hr. = 0.44704 m/sec.

1 m/sec. = 2.23693 mi/hr.

1 lb. = 0.45359 kg.

1 kg. = 2.20462 lb.

1 mi. = 1609.35 m. = 5280 ft.

1 m. = 3.28083 ft.